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Viability of the southern Gulf of St. Lawrence cod population

Viabilité de la population de morue du sud du golfe du Saint-Laurent

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ABSTRACT

The cod population in the southern Gulf of St. Lawrence is currently at a low level of productivity. Unusually high natural mortality of adult cod is the most significant factor in the low productivity of this stock. Slow individual growth also contributes to the low productivity. In contrast, recruitment rate (recruits per unit of spawner biomass), though lower than the unusually high rates observed between the mid 1970s and early 1980s, is currently relatively high compared to the rates observed in the 1950s and 1960s.

Stochastic projections of the southern Gulf cod population were conducted, taking into account recent variability in rates of recruitment and growth and uncertainty both in the natural mortality rate of adult cod (*M*) and in the current levels of cod abundance at age. Projections were made based on each of the four population models examined in the 2008 assessment of this stock. All projections led to the conclusion that the population is not viable at its current level of productivity. Assuming that this low level of productivity persists into the future, the population is expected to steadily decline even with no fishery. Based on the accepted assessment model (which estimates *M* to be 0.59 in recent years), the population is certain to be extirpated (defined here as a spawner biomass less than 1000 t) within 40 years with no fishery and in 20 years with a Total Allowable Catch (TAC) of 2000 t (assuming a catch equal to the TAC or produced by a fishing mortality rate of 3, whichever is less). A substantial increase in productivity would be required for the population to be viable. Assuming an immediate decline in *M* from 0.59 to 0.4, spawner biomass is expected to be stable if there is no fishery. However, even at this higher productivity, a fishery with a TAC of 2000 t would result in extirpation in about 50 years.

RÉSUMÉ

La population de morue du sud du golfe du Saint-Laurent est à un faible niveau de productivité. Le facteur le plus important de la faible productivité du stock est le taux de mortalité naturelle anormalement élevé des morues adultes. Par ailleurs, la lenteur de la croissance individuelle contribue également à la situation. Par contre, le taux de recrutement (recrues par unité de biomasse génitrice), bien qu'il soit plus faible que les taux exceptionnellement hauts observés entre le milieu des années 1970 et le début des années 1980, est actuellement élevé par rapport à ceux des années 1950 et 1960.

Des projections stochastiques de la population de morue du sud du Golfe ont été réalisées en tenant compte de la récente variation des taux de recrutement et de croissance et de l'incertitude dont sont teintées à la fois le taux de mortalité naturelle des morues adultes (*M*) et les niveaux actuels d'abondance de la morue selon l'âge. Des projections ont ainsi été faites à partir des quatre modèles de population examinés au cours de l'évaluation de 2008 de ce stock. Toutes les projections ont mené à la conclusion que la population n'est pas viable au niveau actuel de productivité. Si l'on suppose que ce faible niveau persiste dans l'avenir, la population connaîtra une baisse constante, même sans exploitation. Selon le modèle d'évaluation accepté (qui estime *M* à 0,59 ces dernières années), la population est vouée à la disparition (définie ici comme une biomasse génitrice de moins de 1 000 t) d'ici 40 ans sans pêche et d'ici 20 ans avec un total autorisé de captures (TAC) de 2 000 t (en supposant des captures équivalentes au TAC ou produites par un taux de mortalité par pêche de 3, soit le plus faible des deux). Il faudrait une augmentation substantielle de la productivité pour que la population soit viable. Si l'on suppose une baisse immédiate de *M* de 0,59 à 0,4, la biomasse génitrice devrait demeurer stable en l'absence d'exploitation. Toutefois, même à ce taux élevé de productivité, une pêche avec un TAC de 2 000 se soldera par la disparition de la population d'ici à peu près 50 ans.

INTRODUCTION

Like many other cod populations in the Northwest Atlantic, the cod population in the southern Gulf of St. Lawrence is currently at a low level of productivity (Shelton et al. 2006). The natural mortality of adult cod is unusually high (Sinclair 2001; Chouinard et al. 2005) and appears to be increasing further (Chouinard et al. 2008). Size-at-age in this population declined to a low level in the 1980s and has remained low since then (Sinclair et al. 2002b; Fig. 1a). Recruitment is also currently low, but this reflects the low spawning stock biomass (SSB) rather than a low rate of recruitment (recruits per unit of SSB). Although lower than the unusually high rate observed from the mid-1970s to the early 1980s, the average recruitment rate in the 1990s and 2000s has been greater than that observed in the 1950s and 1960s (e.g., Swain and Sinclair 2000; Fig. 1b).

The purpose of this report is to describe the long-term viability of this population at its current low level of productivity, given fishery removals at levels between 0 and 2000 t annually. This was done by conducting long-term projections of spawner biomass, taking into account the observed variability in rates of recruitment (recruits/SSB) and growth (weight-at-age) and uncertainty in the natural mortality of adults (*M*) and in population size at age in 2008.

METHODS

Stochastic projections were conducted, taking into account recent variability in rates of recruitment and growth and uncertainty in *M*. Projections were done using each of the models examined in the 2008 assessment of this stock (Chouinard et al. 2008). Model 1 used the same formulation as was used in the 2007 assessment, with *M* estimated in 4 blocks of years (1980-1986, 1987-1993, 1998-2002, 2003-2007) and fixed at assumed values of 0.2 in 1971-1979 and 0.4 in 1994-1997. Model 2 was the same as model 1 except that catch rates at ages 2-12 years in the August sentinel trawl survey were included in the model calibration in addition to the abundance indices used in previous assessments. Model 3 assumed that *M* was 0.2 up to 1985 and 0.4 since 1986, and included the August sentinel survey in the calibration. Model 4 was the same as model 2 except that *M* was estimated in 3 blocks of years (1980-1986, 1987-1993, 1998--2007). Model 2 is the preferred model which was selected as the basis for the assessment of the stock. Projections were conducted using Fortran programs.

For all models, projections were made assuming total allowable catches (TACs) of either 0 or 2000 t. For model 2, additional projections were made with TACs of 300 or 500 t. For each model and TAC level, a thousand 100-yr projections were made as follows:

1) Starting population sizes were obtained by randomly selecting one of the 1000 bootstrap replicates of terminal population abundances at age produced when fitting the population model using ADAPT. Ages 3 to 15+ years were used in the projections. This step takes into account the uncertainty in population abundance in 2008.

2) In each year of the projection, *M* was randomly selected from a normal distribution with a mean and standard deviation (SD) equal to the value estimated for *M* in the terminal block of years and the SD of this estimate. For model 3, where an assumed value of 0.4 was used for *M*, a SD of 0.025 was used for projections. This is within the range of SDs observed for *M* when it was estimated (0.020 – 0.027). This step takes into account the uncertainty in *M*.

3) If the TAC was set at 0, fishing mortality F was assigned a value of 0. If the TAC was not set at 0, $F_{i,t}$ (the fishing mortality at age i in year t) was assigned as follows:

i) s_i, partial recruitment at age i, was set to the average for the period 2002, 2004-2007. The partial recruitment is the exploitation pattern of the fishery by age and is determined by the selectivity of the gear and the availability of fish by age within the fishing area. Partial recruitment at age i is fishing mortality at that age as a fraction of fully-recruited fishing mortality.

ii) w_i, weight at age i in the catch, was set to the average for the period 2005-2007

iii) For a given fully-recruited fishing mortality $F_{\bullet,t}$, total catch C_t is given by

$$C_t = \sum_{i=3}^{15} \frac{w_i F_{\bullet,t} s_i N_{i,t} (1 - e^{-F_{\bullet,t} s_i - M_t})}{F_{\bullet,t} s_i + M_t} \qquad (1)$$

where $N_{i,t}$ is the beginning-of-year abundance at age i in year t.

iv) The value of $F_{\bullet,t}$ that minimized the absolute value of TAC-C_t was found using the IMSL subroutine dbcpol with the constraint that $F_{\bullet,t}$ could not exceed 3.0.

v) $F_{i,t} = s_i F_{\bullet,t}$

4) For ages i =4 to 14, abundance at the beginning of year t was given by:

$$N_{i,t} = N_{i-1,t-1} e^{-F_{i-1,t-1} - M_{t-1}} \qquad (2)$$

5) For the plus group i = 15, abundance at the beginning of year t was given by:

$$N_{15,t} = N_{14,t-1} e^{-F_{14,t-1} - M_{t-1}} + N_{15,t-1} e^{-F_{15,t-1} - M_{t-1}} \qquad (3)$$

6) S_t, spawning stock biomass at the beginning of year t, was given by:

$$S_t = \sum_{i=3}^{15} m_i b_{i,t} N_{i,t} \qquad (4)$$

where m_i is the proportion mature at age i (from a maturity ogive estimated from spring samples collected in 1990-1995) and $b_{i,t}$ is the beginning-of-year weight for age i in year t. The value of b_i used for year t was randomly selected from the values observed from 1993 to 2008.

7) Recruitment in year t ($N_{3,t}$) was given by:

$$N_{3,t} = r_t S_{t-3} \qquad (5)$$

where the recruitment rate r_t was randomly selected from the values observed from 1993 to 2008 (year-classes 1990 – 2005).

For illustrative purposes, an additional projection was conducted using the outputs of model 2 but assuming a sudden reduction in M by about one-third, from 0.59 to 0.4.

RESULTS

The cod population in the southern Gulf of St. Lawrence is not viable at its current level of productivity. Assuming that this low level of productivity persists into the future, the population is expected to steadily decline even in the absence of any fishery (Fig. 2), with extirpation

occurring within about 50 to 100 years. Declines are most steep based on the assessment models which estimate recent levels of *M* (models 1 and 2) because these models estimate that *M* has been very high in recent years (0.56-0.59). Models which assume a lower *M* (model 3, *M* assumed to be 0.4 since 1986) or estimate *M* over a longer period (model 4, *M* estimated to be 0.5 since 1998) yield a less steep decline. In all cases, even a small fishery with a TAC of 2000 t significantly accelerates the decline (Fig. 2). Even this small TAC cannot be caught as the stock approaches extirpation, assuming that *F*'s greater than 3.0 cannot be achieved (Fig. 3).

As expected, smaller fisheries (TACs of 300-500 t) have a lesser, but not imperceptible, effect on the rate of decline (Fig. 4 and 5). Defining extirpation as a spawner biomass less than 1000 t, the stock is certain to be extirpated within 38 years (by 2046) if there is no fishery (based on model 2, Fig. 5). With a 2000 t fishery, extirpation occurs twice as quickly (in 20 years, 2028). TACs of 300 or 500 t result in extirpation in 27-29 years.

Using model 2 but assuming an immediate decline in *M* from 0.59 to 0.4, spawner biomass is expected to be stable if there is no fishery (Fig. 6). In this case, TACs of 300-500 t also result in a spawner biomass that is roughly stable, though at a lower level (Fig. 7). However, even at this higher level of productivity, a TAC of 2000 t would result in extirpation in about 50 years (Fig. 6). (Note that this projection is more optimistic than that based on model 3, which also assumes an *M* of 0.4, because recruitment rate is estimated to be somewhat lower based on model 3 than based on the other models.)

DISCUSSION

The southern Gulf cod population is not viable given its current low productivity. Unless productivity increases, it will be extirpated within 50 to 100 years even if there is no fishery. Extirpation is expected to occur considerably more quickly if there is a fishery. Time to extirpation with a TAC of 2000 t is about half that with no fishery. Restricting fishery removals to the lowest possible level will allow the stock to persist longer, increasing the chances that productivity will increase to a sustainable level before the stock is extirpated.

Productivity has three components: recruitment rate, the growth rate of individual fish, and adult survival rate (or conversely, the natural mortality rate of adults). Recent rates of recruitment have been considerably lower than the very high rates observed from the mid 1970s to the early 1980s (Fig. 1). These very high rates fueled the rapid recovery of this stock from its first collapse in the 1970s. However, these earlier rates are thought to be abnormally high, reflecting reduced predation on cod eggs and larvae following the collapse of pelagic fish stocks (herring and mackerel) in the southern Gulf in the early 1970s (Swain and Sinclair 2000). Excluding this period of abnormally low pelagic fish biomass, recent rates of recruitment have been relatively high, over twice the average rate observed in the 1950s and 1960s. At the current level of pelagic fish biomass, there is no reason to expect recruitment rates to increase to even higher levels.

Size-at-age of southern Gulf cod declined sharply in the late 1970s and early 1980s. This decline resulted from a density-dependent decrease in growth rate and the phenotypic response to a change in the direction of size-selective mortality (Sinclair et al. 2002 a,b). Size-at-age of southern Gulf cod has remained low. This is surprising because conditions for growth now appear to be good: the temperatures experienced by cod during the feeding season are relatively warm, cod density is low, and the abundance of their prey is high. The continued slow

growth of southern Gulf cod may reflect a genetic response to the strong selection against fast growth that occurred in the 1980s and early 1990s (Swain et al. 2007a).

Natural mortality of adult southern Gulf cod increased in the 1980s and has been unusually high throughout the 1990s and 2000s (Sinclair 2001; Chouinard et al. 2005). This high natural mortality is the most significant factor in the current low productivity of this stock (Chouinard et al. 2003). Natural mortality now appears to be increasing further (Swain et al. 2007b; Chouinard et al. 2008). If so, our projections (which assume constant average *M* at the current level) are overly optimistic.

A substantial decline in *M* would be required for the population to be viable at the current rates of recruitment and growth. The population would be expected to be stable if *M* declined by about a third, from the current level near 0.6 to a value near 0.4. However, even with this substantial decline in *M* average surplus production would be near zero, and the population would be expected to decline to extirpation with a TAC of 2000 t.

The reason for the elevated natural mortality of southern Gulf cod is uncertain. One hypothesis is that the increase in *M* reflects increased predation by grey seals (Chouinard et al. 2005). If grey seals are preying on cod when they are highly aggregated (e.g., during migration and overwintering periods), their predation success will remain high despite declining cod abundance. If this is the case, it is critical to maintain cod biomass at the highest level possible. This is because the natural mortality caused by a given amount of predation will increase as cod biomass decreases.

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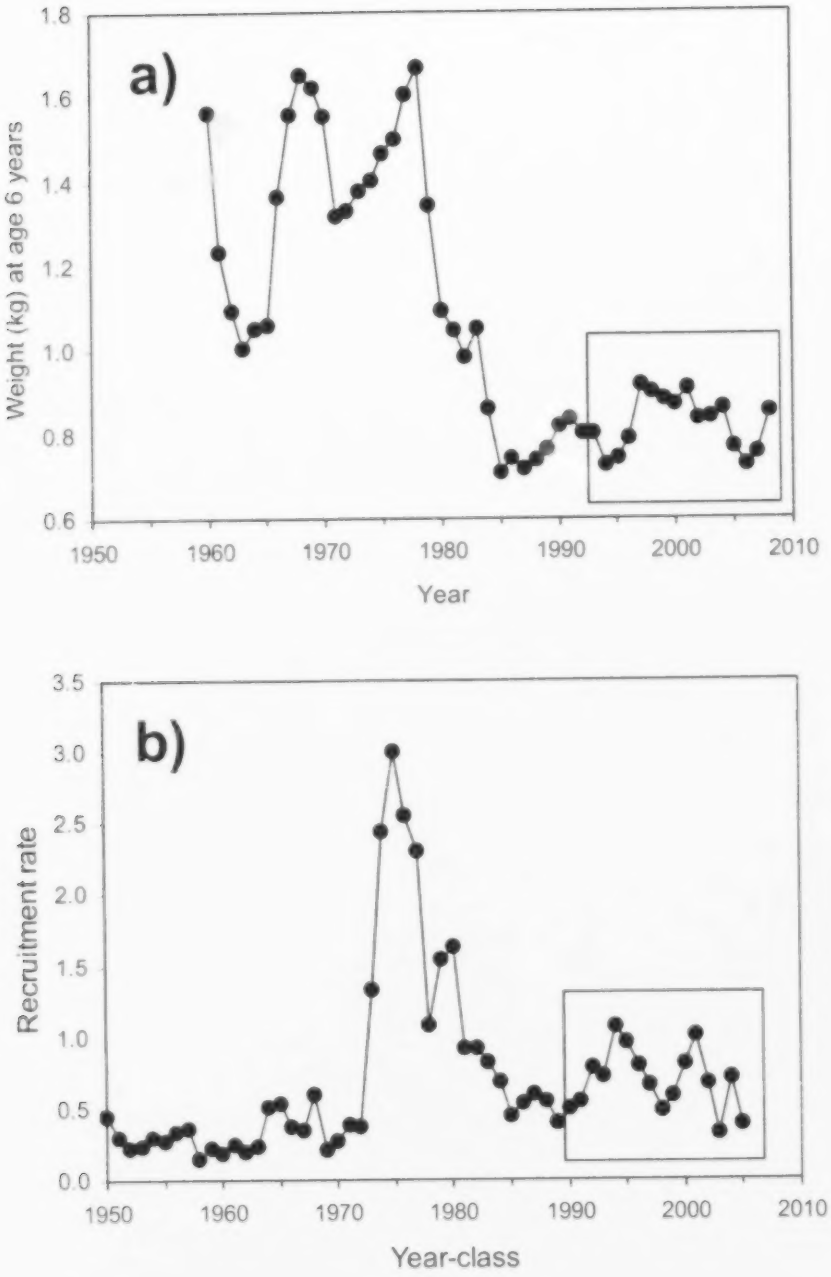

Figure 1. Components of production of southern Gulf of St. Lawrence cod: a) mean beginning-of-year weight at an age of 6 years; b) recruitment rate, based on Model 2 in Chouinard et al. (2008). Boxes indicate the years or year-classes used as input for projections.

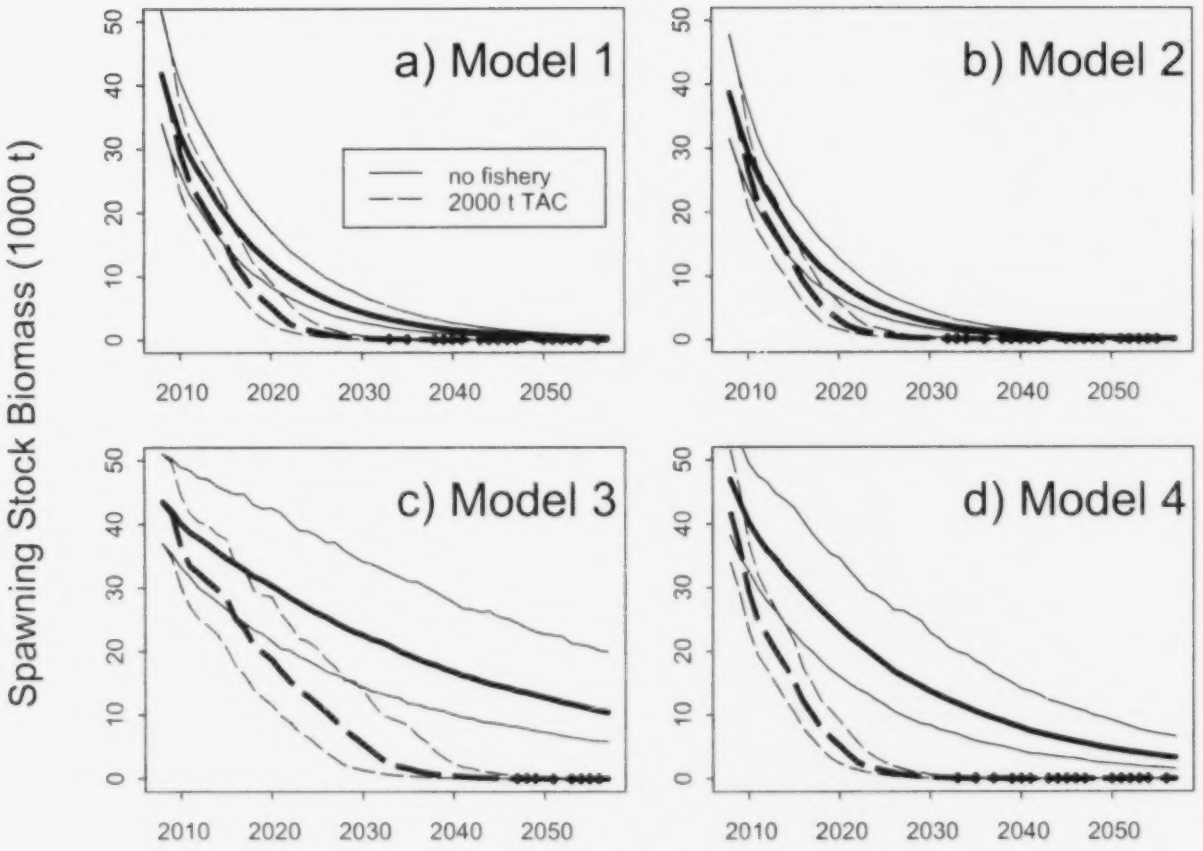

Figure 2. Projections of spawning stock biomass of the southern Gulf of St. Lawrence cod population based on four assessment models (see text for details) and the assumption that productivity remains at the current level indicated by each model. Solid lines are the projection with no fishery and the dashed line is the projection assuming a TAC of 2000 t (fully caught only in the early years of the projection, see Figure 3). Heavy lines show the median projected biomass and light lines the 2.5th and 97.5th percentiles of projected biomass.

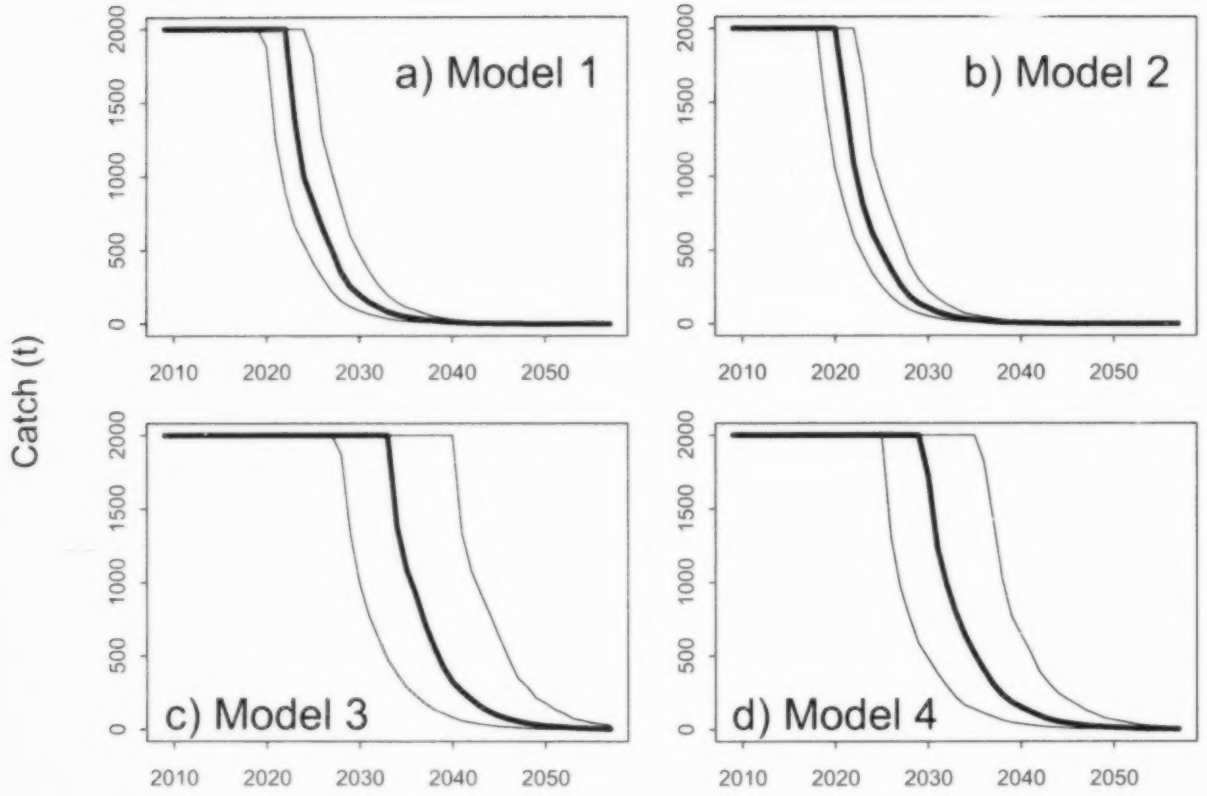

Figure 3. Projected catch of southern Gulf of St. Lawrence cod based on four assessment models (see text for details) and the assumptions that i) productivity remains at the current level indicated by each model, ii) the TAC is set at 2000 t, and iii) the maximum attainable fishing mortality is 3.0. Heavy lines show the median projected catch and light lines the 2.5th and 97.5th percentiles of projected catch.

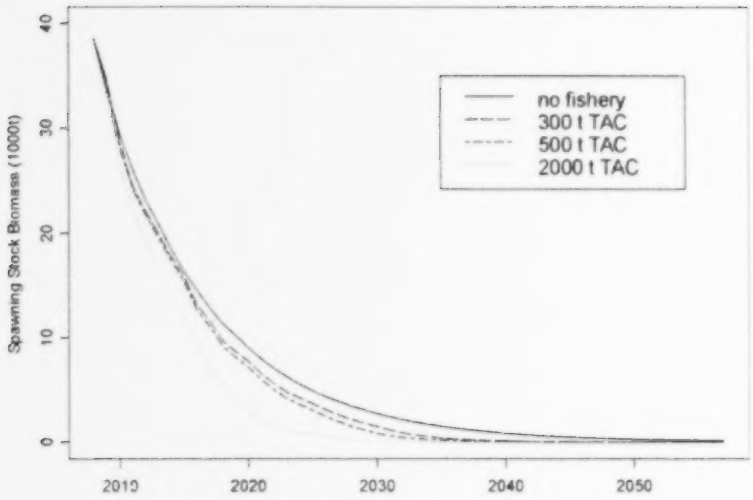

Figure 4. Median projected spawning stock biomass of southern Gulf of St. Lawrence cod based on the preferred assessment model (model 2, see text for details), given four levels of fishing (TAC) and the assumption that productivity remains at the current level indicated by the model.

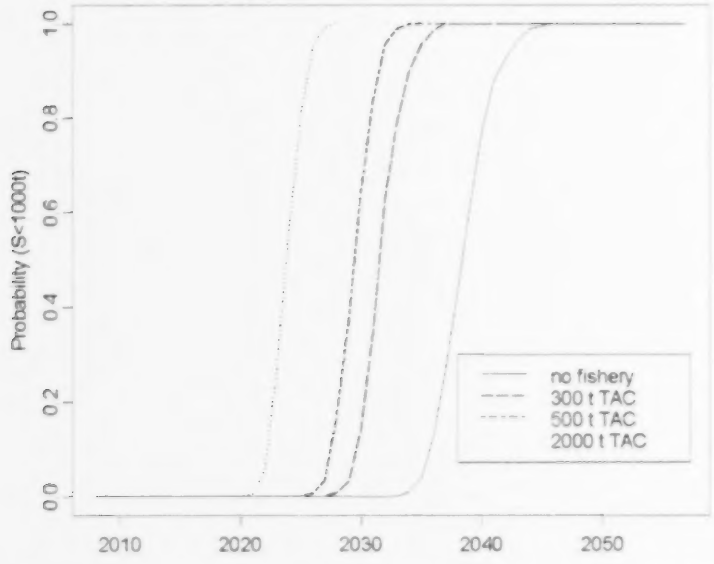

Figure 5. Probability of a spawning stock biomass (S) less than 1000 t for southern Gulf cod based on the preferred assessment model (model 2), given four levels of fishing and the current level of productivity.

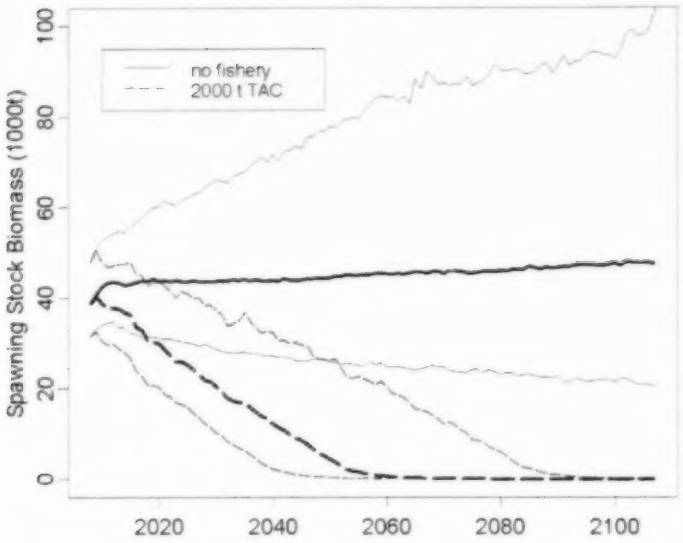

Figure 6. Projections of spawning stock biomass of southern Gulf of St. Lawrence cod based on assessment model 2 (the preferred model) and the assumption that productivity remains at the current level except for an immediate decline in *M* by one third (from 0.59 to 0.4). Solid lines are the projection with no fishery and the dashed line is the projection assuming a TAC of 2000 t. Heavy lines show the median projected biomass and light lines the 2.5th and 97.5th percentiles of projected biomass.

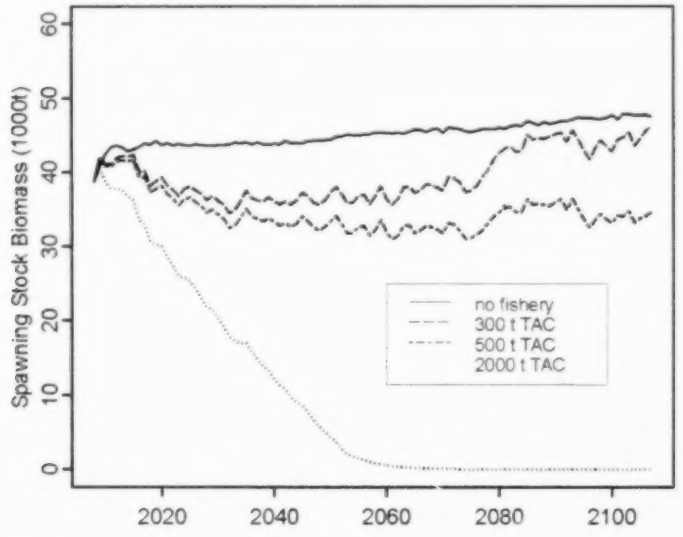

Figure 7. Median projected spawning stock biomass of southern Gulf cod at four levels of fishing based on assessment model 2 and the assumption that productivity remains at the current level except for an immediate decline in *M* by one third (from 0.59 to 0.4).